Ocean Literacy, Climate Change and Health in Coastal Living Environments: A Scoping Review and Bibliometric Analysis (ScoRBA)

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Abstract. This study examines the complex relationships between ocean literacy, climate change, and health in coastal living environments through a scoping review and bibliometric analysis (ScoRBA). Based on the PAGER framework, the research identifies four key themes: frameworks for coastal sustainability, connections betweenoceans and coastal areas, challenges to human health and well-being, and ocean literacy for conservation education and adaptation. A bibliometric analysis of 206 articles published between 2014 and 2023 showed a significant increase in research linking ocean literacy with climate change adaptation and coastal public health. Given the accelerating climate impacts on coastal environments and public health risks, urgent action integrates ocean literacy into adaptation strategies. Delays may cause irreversible damage to ecosystems and human health. The key findings of the current research highlight the importance of integrating marine environment management with human well-being, aligning with the Sustainable Development Goals (SDGs). The study underscores the need for standardized metrics to assess the impact of ocean literacy on climate change adaptation and public health outcomes, as well as the significance of participatory approaches in coastal ecosystem management. The research implicates the necessity for climate change adaptation strategies that explicitly consider public health and the development of ocean literacy programs to enhance understanding of the interconnections between climate change and human health. Future research should focus on developing standardized tools to assess the impact of ecosystem services on coastal community resilience and explore tailoring ocean literacy programs to support climate adaptation and coastal health.

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1 Introduction

Climate change significantly threatens coastal environments and human health. Rising temperatures, sea levels, and ocean acidification alter marine ecosystems, affecting species distribution and abundance [1]. These changes can synergistically affect coastal ecosystems [2]. Human activities have disrupted the ocean's stability, leading to widespread changes in ecological processes and human health [3]. Understanding the interactions between climate change and local human impacts is crucial for predicting future changes, developing conservation strategies, and enhancing coastal communities' adaptation [2]. Addressing these challenges requires an interdisciplinary approach to mitigate the consequences of environmental changes on coastal ecosystems and society [4].

In response to these pressing challenges, ocean literacy has gained traction as a framework for understanding and managing the ocean's complex dynamics. Ocean literacy has evolved into a complex framework, combining understanding, skills, and motivations related to ocean management. Santoro et al. [5] stated that ocean literacy first emerged in the early 2000s in the United States to address the lack of ocean-related content in science education. The National Oceanic and Atmospheric Administration (NOAA) [6] defines ocean literacy as an understanding of how the ocean affects you and how you affect the ocean, which is expanded into seven essential principles and 45 fundamental concepts [7]. UNESCO has declared the period from 2021 to 2030 as the Decade of Ocean Science for Sustainable Development. This declaration highlights the significance of ocean literacy in addressing contemporary environmental issues [8].

Building on the ocean literacy, it becomes evident that climate change's impact on coastal ecosystems and communities is multifaceted and far-reaching. Climate change significantly impacts coastal ecosystems and the communities that depend on them. Neumann et al. [9] identified challenges of climate change such as rising sea levels, more frequent and intense storms, ocean acidification, and changes to marine ecosystems. These conditions impact human health, including injuries from extreme weather, food security, and mental health issues [10]. The accelerated degradation of estuarine and coastal ecosystems because of human activities leads to the loss of essential habitats, such as salt marshes and mangrove forests, which are vital for the economy and protection from natural disasters [11, 13].

Given the interconnectedness of ocean literacy and climate change impacts, understanding how these factors shape coastal communities' responses is crucial. Ocean literacy is essential in coastal communities facing ocean-related challenges and opportunities. Mogias et al. [13] found that while general awareness of ocean issues is increasing, deep ocean literacy is still limited, especially among non-coastal populations. Brennan et al. [14] added that even among coastal populations, there are still significant gaps in understanding the complex interactions of ocean and climate. Satterthwaite et al. [15] point out that increasing marine literacy can improve resource management and sustainable fisheries practices. In addition, Bennett et al. [16] and Fleming et al. [17] confirmed that support for marine protected areas and conservation efforts increases with better marine literacy.

However, there are still a lack of comprehensive studies that explore the integration of marine literacy into formal education and its impact on coastal communities' resilience to climate change. Santoro et al. [5] emphasized the importance of integrating marine literacy

into the formal education system to empower student's decisions about marine resources and sustainability. This is reinforced by Husna et al. [18] who showed that vocational education and training programs in marine science can empower the economy and resource management in coastal areas. Pazoto [19] added that marine literacy education can promote participatory coastal management and a deep understanding of marine ecosystems, which are essential for sustainable development. The interconnectedness between marine literacy and climate change impacts provides important insights into how climate change has already affected the health of coastal communities, both directly and indirectly.

The scoping review and bibliometric analyses in this study identify key themes and trends in marine literacy and the impacts of climate change on coastal communities' health. Despite the increasing focus on ocean literacy, a significant gap exists in exploring how marine literacy influences coastal communities' awareness of climate change and health response. The scoping review of this study will follow the approach suggested by Bradbury-Jones et al. [20] using the PAGER (Patterns, Advances, Gaps, Evidence, and Recommendations) framework [21], to explore current knowledge on the relationship between marine literacy, climate change, and health in coastal areas. The study will also identify gaps in the existing literature and provide recommendations for future research. The main focus of this study is to collate and analyze data on how marine literacy influences coastal communities' awareness of and response to climate change and its impacts on their health.

2 Materials and Methods

This study employed a five-step scoping review methodology to explore the connections between ocean literacy, climate change, and health in coastal environments, using Arksey and O'Malley's framework [22] and bibliometric analysis [23] known as ScoRBA [21]. The research utilized visualization tools like VOSviewer [24] for a comprehensive bibliometric analysis. Bibliometrics, a systematic technique grounded in information and library science, applies statistical and mathematical methods to analyze scientific publications deeply [25, 26]. Ellegaard and Wallin [26] emphasized that bibliometric analysis enables a detailed examination of bibliographic data, assessing publications' quantity, type, and quality. This approach enhances our understanding and application of marine literacy, fostering healthier coastal communities and sustainable marine ecosystems amid rapid environmental change.

The study expands upon this established methodology to map and analyze relevant evidence. The scoping review provides a comprehensive overview of the existing literature, identifies knowledge gaps, and lays the groundwork for future research recommendations Peters et al. [27]. The primary focus of this study is to address the question: 'How do ocean literacy, climate change, and health in coastal environments interact?'

Table 1. Arksey and O'Malley's Research Steps and Methods by Arksey and O'Malley [22].

Steps	Descriptions
Identification of Research	The main research question was "Do ocean literacy, climate change, and health interact in coastal living environments?" The researcher

Steps	Descriptions
Question and Related Studies	conducted a pre-preliminary reading of relevant studies to determine keywords and terms for articles.
Study Selection	Researchers used the Scopus database to select final peer-reviewed, journal-published articles written in English. Articles that assessed the use of ocean literacy, climate change, and health in coastal living environments met the selection criteria for this study.
Data Recording	The researcher used co-occurrence keywords to categorize the data into graphical representations. This study helped to understand how ocean literacy, climate change, and health are interrelated in coastal living environments.
Collating, Summarising, and Reporting Results	Researchers used the Patterns, Advances, Gaps, Evidence of Practice, and Research Recommendations (PAGER) Framework to summarise, analyze, and present results. This approach improves the quality and applicability of the literature review.
Evaluation	Researchers evaluate the results of the approach and make recommendations for future research based on their findings.

Table 1 describes the first step in starting the research. The researcher conducted a literature search on the Scopus database in May 2024. The Scopus database is known for its reputation as an extensive and trusted academic source [28, 29]. Scopus can provide in-depth publication and substantial citation data. The argument following the findings of Wijaya et al. [30] underlined the relevance and reliability of Scopus in providing comprehensive information that supports this study.

Table 2. Search Statategy on Scopus Database

All Search String	
TITLE-ABS-KEY ((“ocean literacy”) AND (“climate change” OR “global warming”) AND (“coastal environments” OR “coastal ecosystems” OR “sea level rise” OR “coastal erosion”)) OR TITLE-ABS-KEY (“ocean literacy” AND (“health impacts” OR “public health” OR “coastal health” OR “climate-related health” OR “environmental health”)) OR TITLE-ABS-KEY (“climate change” AND (“health impacts” OR “public health” OR “coastal health” OR “**climate-related** health” OR “environmental health”) AND (“coastal environments” OR “coastal ecosystems” OR “sea level rise” OR “coastal erosion”))	**418 documents found**
Limitation	
AND PUBYEAR > 2014 AND PUBYEAR < 2023 AND (LIMIT-TO (PUBSTAGE, “final”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (DOCTYPE, “ar”))	**206 documents found**

Following that, the researchers applied a systematic search strategy to identify relevant articles. The initial search results showed 418 documents published from 2014 to September 2023 that met the initial criteria, which were then further filtered based on relevance and quality. The search strategy used Boolean operators by Carcassi and Sbardolini [31] to combine keywords related to marine literacy, climate change, and health in coastal environments. Boolean operators 'AND' and 'OR' were used to filter the data, ensuring the search covered all aspects relevant to the research topic.

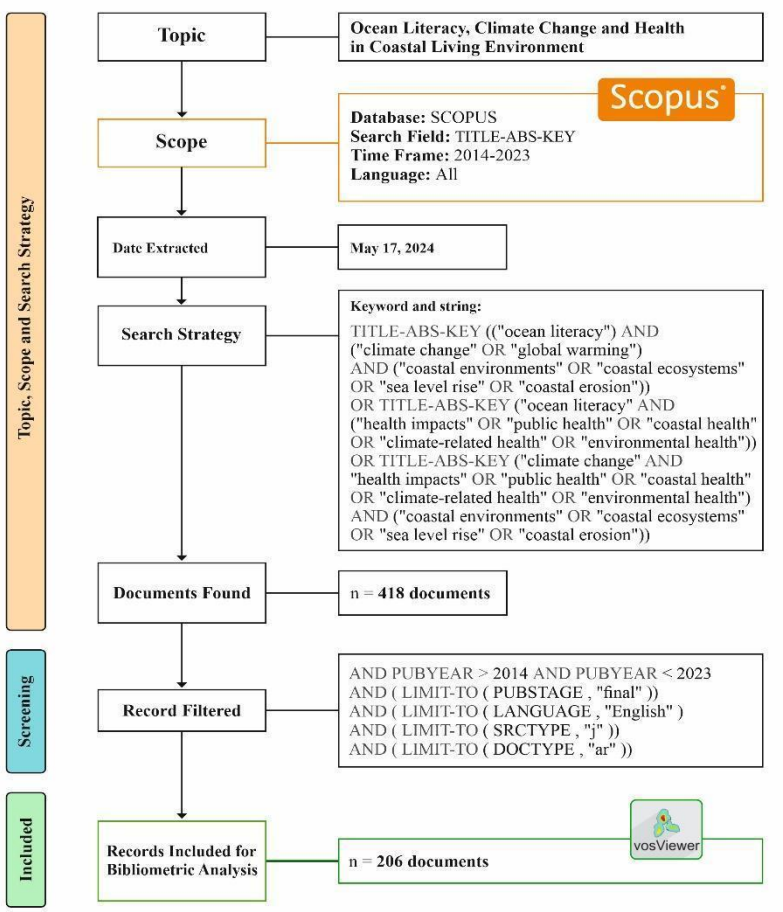


Figure 1. PRISMA flow diagram of the search strategy as adapted from Page et al. [32].

Thirdly, the researchers applied inclusion and exclusion criteria to select relevant articles utilizing the PRISMA flow diagram [32]. Figure 1. provides transparency in the document selection by showing systematic steps in selecting and screening articles. The selection criteria include final articles published in Scopus-indexed journals and written in English. These articles have focused on 'ocean literacy,' 'climate change impacts,' and 'health' in 'coastal environments.' This restriction aims to ensure that the data used is relevant and up-to-date, and reduces the possibility of bias from irrelevant or out-of-date

sources [33]. This step resulted in 206 high-quality, peer-reviewed original articles (finalized documents) that met the criteria for analysis using ScoRBA.

The fourth and fifth steps of the technique are further explained in the data charting and discussion sections. The sections will explain in detail how the data were classified and interpreted to identify key findings and gaps in the literature. The processes helped summarize the information as the focus of future research and provided insights into the relationship between marine literacy, climate change, and health in coastal environments.

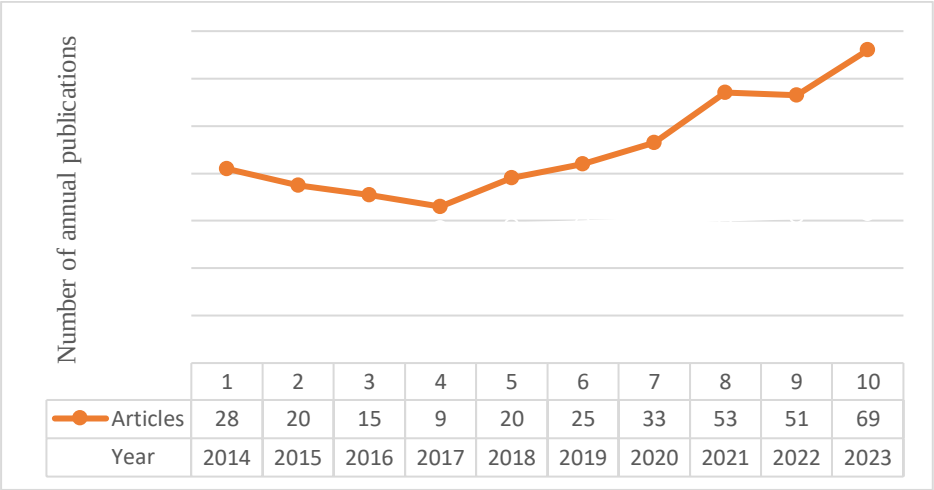
3 Results

The results of the initial literature search showed 418 documents between 2014 and 2023, with 206 articles meeting the inclusion and exclusion criteria for further analysis.

3.1 Publication Output

The findings presented in Table 3 show a consistent upward trend in publications from 2014 to 2023 related to ocean literacy, climate change, health, and coastal environment, with a significant acceleration in the last three years. The increase reflects the growing interest in research examining the interactions between these three topics.

Table 3. Annual publication in the Scopus database. Term ocean literacy, climate change, and coastal health research from 2018 to 2023



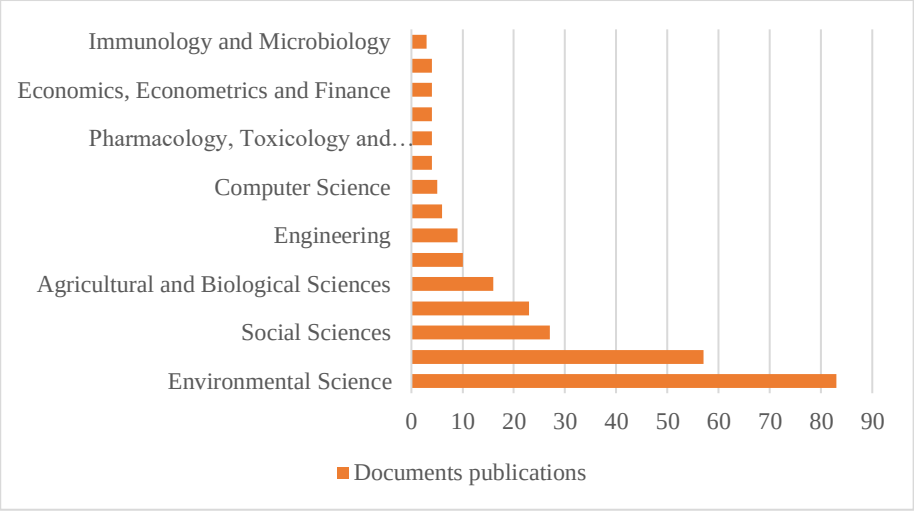
	1	2	3	4	5	6	7	8	9	10
Articles	28	20	15	9	20	25	33	53	51	69
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023

The trend above aligned with UNESCO's [8] establishment of the Decade of Ocean Science for Sustainable Development for 2021-2030, which emphasizes the importance of ocean literacy as a response to contemporary environmental challenges. The response highlights the urgent need to improve global understanding of the oceans and promote ocean literacy as a key strategy in dealing with climate change and maintaining the sustainability of coastal ecosystems. Santoro et al. [5] revealed that increased attention to ocean literacy is part of global efforts to address the impacts of climate change, which is in line with UNESCO initiatives.

In addition, a recent report from NOAA [6] provides in-depth data on the impacts of climate change on coastal environments and human health, underscoring the importance of improving marine literacy. These findings strengthen the argument that there is an increasingly urgent need to integrate ocean literacy into climate change adaptation and mitigation strategies.

The distribution of subject areas and research results on 'ocean literacy,' 'climate change impacts,' and 'health' in 'coastal environments' spans a wide range of disciplines, demonstrating complex interrelationships and the multidisciplinary nature of these topics. Table 4 lists 15 subject areas of which five most prominent are environmental science (31.5%), medicine (21.5%), social sciences (10.2%), earth and planetary sciences (8.7%), and agricultural and biological sciences (6.6%).

Table 4. Top 15 research subjects on the Scopus database.



The distribution in the table above highlights that marine literacy, climate change, and health in coastal environments are not only environmental issues but also public health, social, and scientific ones. Thus, this multidisciplinary distribution highlights the complexity and interconnectedness of the research topics, reflecting the importance of a holistic and integrative approach in understanding and addressing the challenges faced by coastal environments in the era of climate change.

3.2 Data Charting

Data charting, the fourth step of this study, results in outcomes presented in Table 5. As described by Arksey and O'Malley [22], traditional narrative reviews usually focus on the main themes or concepts in the literature descriptively. Co-occurrence and keyword analysis, as a quantitative approach, allows for the identification of hidden patterns, correlations, and themes that may not be apparent through a typical narrative approach and greater depth of analysis by revealing complex keyword network structures and relationships between themes.

Bibliometric analysis using VOSviewer, as described by van Eck and Waltman [34], allowed in-depth exploration of 418 documents downloaded from the Scopus database. From the 1,015 keywords initially identified, 164 of them (refer to 1015) appeared at least twice for further analysis. The results demonstrated the existence of four clusters in the keyword network illustrated in Figure 4. These clusters reflect the complexity of the relationship between ocean literacy, climate change, and health in coastal environments. The study used the ScoRBA framework [21] to uncover complex relationships between different aspects of coastal environmental management, providing a foundation for future interdisciplinary research and evidence-based policy development in the face of global challenges of climate change and ocean conservation.

Data charting results, described in Figure 2, show that cluster 1 (Red) focuses on the framework for coastal sustainability, highlighting key elements such as ocean governance, human impacts, biodiversity, and the blue economy. Cluster 2 (Green) connects the ocean and coastal areas, linking marine ecosystems to human well-being through community participation, environmental attitudes, and human health. Cluster 3 (Blue) highlights addressing challenges to human health and well-being and the risk of sea level rise, demonstrating the close relationship between ocean conditions and healthy people in coastal areas. Cluster 4 (Yellow) focuses on ocean literacy for educating and conservation adaptation, emphasizing the importance of environmental education and scientific communication to support conservation and sustainable ocean management. This approach reinforces the argument that a deep understanding of these relationships is essential for developing effective strategies to deal with environmental challenges in the era of Society 5.0.

Table 5. Four clusters and themes in this study

Cluster	Color	Number of keywords	Focus	Main of Keyword
1	Red	27	A framework for coastal sustainability	Ocean governance, human impact, biodiversity, blue economy
2	Green	21	Connecting the ocean and coastal areas	Citizen science, environmental attitude,
3	Blue	16	Addressing challenges to human health and well-being	Health, public health, well-being, sea level rise
4	Yellow	13	Ocean literacy for educating and conservation adaptation	Environmental education, marine conservation communication, science communication

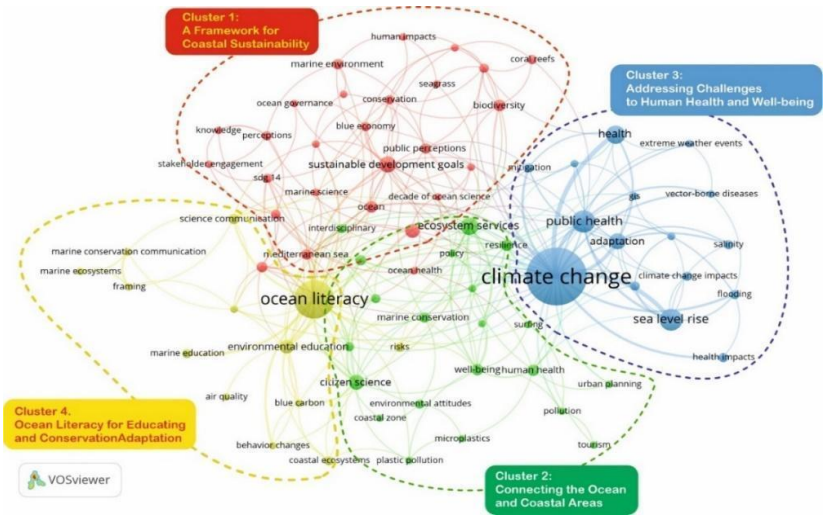


Figure 2. Visualization results of 206 co-occurrences of author's keywords.

4 Discussion

This study discovers that the researchers deliberated on four significant themes about coastal sustainability: frameworks for coastal sustainability, connecting oceans and coastal areas, addressing challenges to human health and wellbeing, and ocean literacy for conservation education and adaptation. Each of these subjects encompasses current advancements in research, areas that require further investigation, empirical support for practical application, and recommendations for future study. These conversations enhance the comprehension of the difficulties and possibilities in attaining coastal sustainability.

Table 6. Results of the PAGER analysis of the clusters and themes in this study by Bradbury-Jones et al. [20]

Pattern	Advances	Gaps	Evidence for Practice	Research Recommendation
A Framework for Coastal Sustainability	- Integration of marine environment management with human well-being [35] - UN Decade of Ocean Science for Sustainable Development Momentum	- Lack of understanding of the direct impacts of ocean literacy on climate change adaptation and public health [36] - Need for systematic	- Successful integration of SDGs in coastal management practices enhancing biodiversity and community resilience [37]	- Develop metrics to assess the impact of ocean literacy on climate change adaptation and public health outcomes [38] - Integrate social and behavioral research

Pattern	Advances	Gaps	Evidence for Practice	Research Recommendation
	- Substantial development of marine economy [36]	reviews to understand interconnections between sustainable practices and long-term impacts	- Ecosystem-based management approaches improve marine biodiversity and support local livelihoods	methods to assess the effectiveness of ocean literacy initiatives
Connecting the Ocean and Coastal Areas	- Interconnectedness between marine ecosystems and human well-being [39] - Understanding ecosystem impacts such as wildfires and poleward migration on equatorial biodiversity [40]	- Limited standardized measures to evaluate the effectiveness of ecosystem service-based approaches [41] - Need for comprehensive evaluation systems to assess ecological vulnerability	- Participatory approaches and citizen science projects enhancing community engagement [42] - Community participation is crucial in managing marine conservation areas	- Create standardized tools for assessing the impact of ecosystem services on coastal community health and resilience [43] - Develop ecosystem service frameworks for the deep sea to inform decision-making and conservation strategies
Addressing Challenges to Human Health and Well-being	- Detailed understanding of climate change impacts on coastal communities [44] - Focus on health risks and adaptation strategies	- Gaps in integrating public health considerations into climate change adaptation strategies [45] - Need to prioritize	- Successful climate adaptation strategies incorporating health considerations [46] - Green infrastructu	- Design climate change adaptation strategies explicitly addressing public health outcomes [47] - Redefine vulnerability to include health

Pattern	Advances	Gaps	Evidence for Practice	Research Recommendation
		health impacts in climate change adaptation efforts	re and sustainable transportation are effective in mitigating climate change impacts in urban areas	indicators in adaptation planning for sea-level rise
Ocean Literacy for Educating and Conservation Adaptation	- Increasing public understanding of marine issues through education [48] - Significant growth in ocean literacy research	- Need to understand how ocean literacy programs support climate adaptation and coastal health [49] - Necessity of integrating social and behavioral research methods	- Educational programs linking ocean health, climate change, and human health leading to behavioral changes [50] - Awareness of ocean literacy principles associated with increased conservation engagement	- Explore tailoring of ocean literacy programs to enhance understanding of connections between ocean health, climate change, and human health [37] - Improve educational investments from an early age to enhance environmental perception and action

4.1 A Framework for Coastal Sustainability

Marine environment management with human well-being is a cornerstone of the Sustainable Development Goals (SDGs), particularly emphasizing how sustainable development practices can bolster marine biodiversity and coastal management. [35] articulate that the United Nations Decade of Ocean Science for Sustainable Development provides critical momentum for reshaping ocean management narratives, fostering positive actions, and driving toward sustainable marine practices. This alignment with SDGs underscores the

necessity of holistic approaches that marry environmental sustainability with socio-economic benefits.

This perspective is further reinforced by Laffoley et al. [51] who argued that achieving the SDGs related to marine conservation requires a transformative change in managing and interacting with ocean ecosystems. They highlight the need for innovative governance structures and cross-sectoral collaboration, laying the groundwork for more integrated approaches.

However, despite these advancements, a significant gap lies in understanding the direct impacts of ocean literacy on climate change adaptation and public health improvements in coastal communities. Wang et al. [36] point out that while substantial progress has been made in developing the marine economy, systematic reviews are still needed to fully grasp the interconnections between sustainable practices and their long-term impacts. More nuanced research is required to elucidate how education and awareness initiatives directly influence adaptive behaviors and health outcomes in these vulnerable communities.

The evidence from various case studies illustrates the successful integration of SDGs into coastal management practices, enhancing biodiversity and community resilience. For instance, Barradas and Ghilardi-Lopes [37] showcased how ecosystem-based management approaches have effectively improved marine biodiversity while supporting local livelihoods through enhanced environmental perception and management. Such examples provide a replicable model for other regions, demonstrating the practical benefits of aligning development goals with environmental sustainability.

Furthermore, Babinard et al. [52] highlighted the importance of incorporating social equity and environmental justice in marine conservation efforts. Their work runs through integrating these principles into SDG implementation leading to more effective and sustainable outcomes for ecosystems and coastal communities.

Future research should focus on developing robust metrics to assess the impact of ocean literacy on climate change adaptation and public health outcomes in coastal areas [38]. Establishing standardized measures is crucial for better evaluating and improving educational programs that foster sustainable practices. Ashley et al. [49] suggest integrating social and behavioral research methods to assess the effectiveness of ocean literacy initiatives in promoting sustainable solutions. This approach will provide more targeted recommendations and create educational frameworks that effectively support environmental and public health goals.

4.2 Connecting the Ocean and Coastal Areas

The need for a more integrated approach becomes even more apparent when considering the interconnectedness between marine ecosystems and coastal areas. This connection, often encapsulated in the concept of ecosystem services, underscores the critical importance of these services for coastal communities [39]. As researchers delve into the impacts of ecosystem changes, such as those caused by wildfires and poleward migrations, they also see the necessity of addressing these multifaceted challenges through comprehensive conservation strategies.

Herbert-Read et al. [40] discuss how ecosystem impacts, including wildfires and poleward migration, affect marine biodiversity and coastal ecosystems. This idea is for

developing comprehensive conservation strategies that account for the dynamic nature of marine-coastal interactions. Barbier [12] further elaborates on the economic value of marine ecosystem services, highlighting their role in supporting coastal livelihoods and economic development. His work underscores the need for policies that safeguard these services to ensure sustainable coastal economies.

Despite recognizing the importance of ecosystem services, a notable gap persists in the lack of standardized measures to evaluate the effectiveness of these approaches on coastal resilience and development. Peng et al. [41] highlight the need for comprehensive evaluation systems that can accurately assess ecological vulnerability and the effectiveness of ecosystem services in maintaining sustainable development in coastal areas. This gap requires more rigorous and systematic approaches to evaluate and optimize the benefits provided by ecosystem services.

Participatory approaches and citizen science projects offer promising avenues for enhancing community engagement and data collection on coastal ecosystem changes. Paulus et al. [42] asserted that community participation is prominent in effectively managing marine conservation areas and correlates with coastal regions. These initiatives foster a sense of ownership and responsibility among coastal community members and provide valuable insights that can inform better management practices. Such participatory approaches are essential for ensuring that ecosystem services are recognized and preserved for the benefit of coastal areas and their inhabitants.

Complementing this perspective, Pascual et al. [53] argued that diverse values and knowledge systems are leading factors in assessing ecosystem services. Their work highlights the importance of considering cultural and traditional ecological knowledge alongside scientific approaches to fully capture the value of marine ecosystems for coastal communities and their economies.

Future research should aim to create standardized tools for assessing how ecosystem services impact coastal community development and resilience to enhance the practical implementation of ecosystem services in linking seas and coastal regions. La Bianca et al. [43] recommend developing ecosystem service frameworks specifically for the deep sea to inform decision-making and conservation strategies that benefit coastal areas. These frameworks provide a structured approach to understanding and leveraging ecosystem services to help coastal communities and their marine environments.

4.3 Addressing Challenges to Human Health and Well-being

The interconnectedness between ecosystem services and coastal resilience naturally extends to the critical issue of human health and well-being in the face of climate change. Understanding the impacts of climate change on coastal communities is essential, particularly concerning health risks and the need for adaptation strategies to protect human well-being. Brewington et al. [44] provide a detailed analysis of climate change impacts on coastal communities, highlighting how these changes exacerbate health threats in vulnerable regions like the Marshall Islands. Their work emphasizes the critical need for adaptive strategies that address these health risks, providing a comprehensive view of the challenges and opportunities related to climate change adaptation in coastal areas.

Extending this perspective, Temmerman et al. [54] argue that ecosystem-based coastal adaptation strategies aim to protect human health and well-being. Their research demonstrates how natural coastal ecosystems can provide effective and sustainable protection against climate change impacts, offering a compelling alternative to traditional engineered solutions that support community health outcomes.

However, integrating public health considerations into climate change adaptation strategies for coastal communities remains a significant gap. Nag [45] points out that prioritizing health impacts, while adapting to climate change, is crucial to ensure that all aspects of human well-being are addressed. A multidisciplinary approach, therefore, may incorporate health outcomes in climate adaptation planning, making strategies more holistic and effective in protecting coastal populations.

Successful climate adaptation strategies incorporate health considerations and demonstrate improved outcomes for coastal populations' well-being. Dano et al. [46] found that green infrastructure and sustainable transportation initiatives mitigate the health impacts of climate change in urban coastal areas. Incorporating health considerations into adaptation strategies is beneficial and aspiring for other regions to follow strategies in addressing the health challenges posed by climate change.

To further this goal, researchers should focus on designing climate change adaptation strategies that explicitly address public health outcomes for coastal communities. Bloetscher et al. [47] recommend redefining vulnerability to include health indicators in adaptation planning when the sea level rises.

4.4 Ocean Literacy for Educating and Conservation Adaptation

Align with the need for holistic and integrated approaches to coastal resilience, ocean literacy emerges as a crucial component in fostering sustainable behaviors and conservation efforts. It can be improved by increasing public understanding and awareness of marine issues through education and communication. Keywords such as "ocean literacy," "environmental education," and "marine conservation communication" shed light on the critical role of education in driving conservation efforts. Salazar-Sepúlveda et al. [48] found significant growth in ocean literacy research, primarily for promoting marine conservation.

Building on this foundation, Stoll-Kleemann [55] voiced the significance of ocean literacy in fostering marine citizenship. His work demonstrates how increased knowledge and understanding of marine issues can lead to greater public engagement in sustainable conservation practices.

Reinforcing ocen literacy remains questionable to understand how it can specifically support climate adaptation and improve coastal health. Ashley et al. [49] noted that integrating social and behavioral research methods vitally can assess the impact of ocean literacy on behavior change. It points out that more targeted research is required to address how ocean literacy programs can support adaptive behaviors and health outcomes.

Educational programs that successfully link ocean health, climate change, and human health have been proven effective in changing public behavior. O'Halloran and Silver [50] found that awareness of ocean literacy principles increases engagement in conservation activities. These programs provide a model for how targeted education can lead to meaningful

changes in public attitudes and actions, fostering a more sustainable relationship with the marine environment.

Complementing these findings, Fauville et al. [7] spotted the role of digital technologies in enhancing ocean literacy. Their research highlights how innovative educational tools and platforms can expand the reach and effectiveness of ocean literacy programs, particularly among younger generations.

Given the demonstrated impacts of ocean literacy on fostering sustainable practices, research should explore how ocean literacy can further enhance public understanding of the connections between ocean health, climate change, and human health. Barradas and Ghilardi-Lopes [37] suggest that environmental education needs to be invested in from an early age to enhance environmental perception and action.

4.5 Limitations

While this paper provides a comprehensive overview of the interconnections between marine conservation, coastal community health, and sustainable development, it is important to acknowledge its limitations. The broad scope of the topics covered, while offering a holistic view, may not allow for in-depth exploration of specific regional challenges or localized solutions. The published literature rapidly conveys evolving issues. Additionally, the paper was primarily drawn from academic sources, potentially overlooking valuable insights from gray literature or traditional ecological knowledge. The complex structure of marine ecosystems and their interactions with human societies implies that some subtleties and site-specific elements were completely addressed in this study. Furthermore, the rapidly changing nature of climate change impacts and policy landscapes demands ongoing adaptation of sustainable conservation strategies. Future research should address these limitations by incorporating more diverse sources of knowledge, conducting region-specific case studies, and regularly updating findings to reflect the latest developments in this dynamic field.

5 Conclusion

This study reported the complex relationships between marine literacy, climate change, and health in coastal environments, emphasizing the importance of interdisciplinary approaches in addressing global challenges. The bibliometric analysis identified four main clusters: a framework for coastal sustainability, connecting oceans and coastal areas, addressing challenges to human health and well-being, and marine literacy for conservation education and adaptation. The findings show increasing interest in research that integrates these aspects and aligns with global initiatives such as UNESCO's Decade of Marine Science. However, significant gaps remain, especially in understanding the direct impacts of marine literacy on building adaptive strategies towards climate change and the health of coastal communities. Evidence shows that a holistic approach combining ecosystem-based management, community participation, and marine literacy programs can improve biodiversity, community resilience, and health. Future studies should include standardized measures to assess the success of marine literacy programs, health issues in climate change adaptation methods, and an investment in early environmental education. Despite limitations in coverage and data

sources, this study piques the importance of interdisciplinary collaboration and sustainable adaptation in facing complex environmental challenges in the era of Society 5.0.

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